AX.25 AMATEUR PACKET-RADIO LINK-LAYER PROTOCOL

VERSION 2.0
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AX.25 Amateur Packet-Radio Link-Layer Protocol

Version 2.0
October 1984

By

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This protocol is intended as a guide to aid in the design and use of amateur packet-radio systems, in order to ensure link-layer compatibility between stations. The existence of this protocol does not preclude anyone from designing, marketing or using products, processes or procedures not conforming to the protocol. This protocol is subject to periodic review, and users are encouraged to use the latest edition.

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Foreword

Packet radio is a mode of communications that will link Amateur Radio stations together directly or by means of a network. It is based on the latest technology, provides error-free communications, channel sharing by many stations, and automatic routing throughout a global data network.

Amateur packet-radio local networks exist in a number of areas throughout North America and overseas. As this is written, amateurs are cascading packet repeaters up and down the East and West Coasts to extend the range of individual stations on VHF. Experimental packet-radio contacts are taking place on the HF bands, via the AMSAT OSCAR 10 satellite, and using VHF meteor-scatter propagation. All these stations and networks can talk to one another only if common standards are used.

This link-layer protocol document represents the culmination of several years of work by amateurs to develop a standard protocol for global use. The <u>link layer</u> is level 2 of the International Organization for Standardization (ISO) seven-layered reference model of Open Systems Interconnection (OSI). The other layers needed for amateur packet radio are now under active consideration.

This link-layer protocol is not simply a paper exercise. The written definition has existed in its original form since 1982, and has undergone evolutionary improvements over these past two years. Operationally proven link-layer software versions have kept pace with protocol agreements. The result is a mature protocol that has been validated by practical software over a two-year period of development.

I would like to acknowledge the special contributions made to this protocol by the author, Terry Fox, WB4JFI, the amateur packet-radio organizations who cooperated in the development and implementation of this protocol, and the ARRL Ad Hoc Committee on Digital Communication, created by the League's Board of Directors, as a recognized medium for presenting standards proposals and resolving differences.

David Sumner, K1ZZ
General Manager

Preface

Note: This preface is not a part of the protocol.

This is the first edition of AX.25 Amateur Packet-Radio Link-Layer Protocol (Version 2.0, October 1984) published by the American Radio Relay League. It was approved by the ARRL Board of Directors in October, 1984. The ARRL was designated the international clearinghouse for information relating to packet radio with a view to encouraging common standards and regulations on behalf of the International Amateur Radio Union (IARU) by their Administrative Council at their meeting in Paris during July, 1984.

Earlier implementations of this protocol were based on a paper given at the Second ARRL Amateur Radio Computer Networking Conference in March 1983. Changes introduced since that paper are bracketed ([ ]).

Major sections within this specification have been organized and numbered in a manner similar to that of International Telegraph and Telephone Consultative Committee (CCITT) Recommendation X.25.

This document defines a protocol to be used between two Amateur Radio stations in a point-to-point communications environment. It specifies only link-layer functions. Other than certain interface requirements to and from other layers, this protocol is not meant to specify any other layer.

This protocol recognizes that the Amateur Radio operating environment is unique, and takes this into consideration. A key feature is the inclusion (at this layer) of repeater stations and repeater linking. These repeater stations simply extend the RF range of Amateur Radio stations. Since they do not impose any flow controls, data switching, or routing, their inclusion at this layer does not imply any network-layer functions. It is anticipated that repeater stations will be phased out (or at least their number greatly reduced) when a true network layer becomes operational.

History

Over the years there have been several link-layer protocols suggested for amateur packet radio. The first link-layer protocol to achieve widespread use was created by Douglas Lockhart, VE7APU, of the Vancouver (BC) Amateur Digital Communications Group (VADCG). It was based on the IBM SDLC protocol and implemented on a packet-radio controller board designed and built by VADCG. This protocol was used for the first few years of amateur packet-radio activity. One of the limitations of the VADCG protocol was that it used a single octet (8 bits) for the station address. This restricted the number of stations to 254 or a smaller number, depending on how the addressing scheme

was implemented. It also required that someone had to assign these arbitrary addresses to each amateur in a local area.

In early 1982, the Amateur Radio Research and Development Corporation (AMRAD) began a study of the link-layer protocols in commercial use at the time. The intent was to recommend a protocol that would not suffer from major limitations in a few years, after packet radio had grown. The result of this study was a recommendation for the use of a slightly modified version of the CCITT X.25 level 2 LAPB protocol standard, which could be considered a subset of the American National Standards Institute (ANSI) Advanced Data Communications Control Procedure (ADCCP), balanced mode.

In June, 1982, a series of meetings was held by AMRAD and the Radio Amateur Telecommunications Society (RATS) of New Jersey. An exploratory meeting was held at Bell Laboratories. Two definitive meetings in which the prototype of AX.25 protocol was developed took place in Vienna, Virginia. Involved at those meetings were Gordon Beattie, N2DSY; Jon Bloom, KE3Z; Dave Borden, K8MMO; Terry Fox, WB4JFI; Paul Rinaldo, W4RI; and Eric Scace, K3NA. Both link- and network-layer protocols were defined at that time. Since both layers were based on the CCITT X.25 recommendation, it was decided to follow the pattern set by AT&T (BX.25 for Bell X.25) and call this new protocol AX.25, for Amateur X.25. The link-layer protocol was then documented by Terry Fox and circulated to other packet-radio experimenters for comment. The network-layer proposal was held for further study. Eric Scace was able to provide invaluable insight into CCITT X.25 as he was one of its authors.

The next step in the evolution of AX.25 was taken in October of 1982. Thomas Clark, W3IWI, president of The Radio Amateur Satellite Corporation (AMSAT), hosted a gathering of most of the leaders in amateur packet radio at that time. AMRAD, AMSAT, the ARRL Ad Hoc Committee on Amateur Radio Digital Communication, Pacific Packet Radio Society (PPRS), St. Louis Amateur Packet Radio (SLAPR), and Tucson Amateur Packet Radio Corporation (TAPR) were represented. The AMRAD version 1.1 AX.25 link-layer protocol was slightly modified and adopted at this meeting.

Had AX.25 remained merely an agreeable concept, this document would not exist today. It is due to yeoman efforts in software development of the AX.25 protocol implementations that packet radio flourishes today. Shortly after the October, 1982, meeting at AMSAT, AX.25 packet signals began to appear. The rapidity with which AX.25 was integrated into the TAPR TNC board was due to the unstinting efforts of the TAPR software development crew, primarily such stalwart packet-radio enthusiasts as Dave Henderson, KD4NL; Margaret Morrison, KV7D; and Harold Price, NK6K. The original VADCG board was soon running AX.25 as well, thanks to Hank Magnuski, KA6M, who modified the original Lockhart software to execute the new protocol.

The first public release of the AX.25 link-layer protocol was in a paper given at the Second Amateur Radio Computer Networking Conference, in March, 1983. Some corrections and changes have been made since then by the ARRL Ad Hoc Committee on Amateur Radio Digital Communication. In July, 1983, West Coast packet groups met to form WESTNET -- to link packet-radio repeaters from San Diego to San Francisco. The WESTNET group decided to extend the AX.25 link-layer address field to accommodate up to eight repeaters. This modification was accepted by the ARRL Committee at their November, 1983,

meeting in Washington, DC. Unresolved at that meeting was the handling of the poll/final bit. When the Committee met again at Trenton, NJ, in April, 1984, Phil Karn, KA9Q, proposed a solution to the poll/final bit problem. His proposal was published in QEX and packet-radio club newsletters, and later adopted by the Committee.

It is fitting, given the history of collective effort by packet-radio pioneers, that this document is the work of many. Special thanks are due to Chuck Green, NØADI; Lyle Johnson, WA7GXD; Phil Karn, KA9Q; Paul Newland, AD7I; Harold Price, NK6K; and Eric Scace, K3NA, for their perceptive and helpful comments.

ARRL Ad Hoc Committee on Digital Communication

This protocol was finalized and approved for submission to the ARRL Board of Directors by the Ad Hoc Committee on Digital Communication. Committee approval of this protocol does not necessarily imply that all committee members voted for its approval. At the time it approved of this protocol, the Committee was comprised of:

Paul L. Rinaldo, W4RI, Chairman
Marshall Quiat, AGØX, Board Liaison
Dennis Connors, KD2S
Terry Fox, WB4JFI
Lyle Johnson, WA7GXD
Douglas Lockhart, VE7APU
Wally Linstruth, WA6JPR
Henry S. Magnuski, KA6M
Paul Newland, AD7I
Eric L. Scace, K3NA

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2* AX25 Link-Layer Protocol Specification

2.1 [Scope and Field of Operation

In order to provide a mechanism for the reliable transport of data between two signaling terminals, it is necessary to define a protocol that can accept and deliver data over a variety of types of communications links. The AX.25 Link-Layer Protocol is designed to provide this service, independent of any other level that may or may not exist.]

This protocol conforms to ISO Recommendations 3309, 4335 (including DAD 1&2) and 6256 high-level data link control (HDLC) and uses some terminology found in these documents. It also conforms with ANSI X3.66, which describes ADCCP, balanced mode.

[This protocol follows, in principle, the CCITT X.25 Recommendation, with the exception of an extended address field and the addition of the Unnumbered Information (UI) frame. It also follows the principles of CCITT Recommendation Q.921 (LAPD) in the use of multiple links, distinguished by the address field, on a single shared channel.]

As defined, this protocol will work equally well in either half- or full-duplex Amateur Radio environments.

This protocol has been designed to work equally well for direct connections between two individual amateur packet-radio stations or an individual station and a multiport controller.

This protocol allows for the establishment of more than one link-layer connection per device, if the device is so capable.

This protocol does not prohibit self-connections. A self-connection is considered to be when a device establishes a link to itself using its own address for both the source and destination of the frame.

[Most link-layer protocols assume that one primary (or master) device (generally called a DCE, or data circuit-terminating equipment) is connected to one or more secondary (or slave) device(s) (usually called a DTE, or data terminating equipment). This type of unbalanced operation is not practical in a shared-RF Amateur Radio environment. Instead, AX.25 assumes that both ends of the link are of the same class, thereby eliminating the two different classes of devices. The term <u>DXE</u> is used in this protocol specification to describe the balanced type of device found in amateur packet radio.]

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* All paragraph numbers begin with 2 to indicate the OSI protocol level.

2.2 Frame Structure

Link layer packet radio transmissions are sent in small blocks of data, called <u>frames</u>. Each frame is made up of several smaller groups, called <u>fields</u>. Fig. 1 shows the three basic types of frames. Note that the first bit to be transmitted is on the left side.

First
Bit Sent

Flag	Address	Control	FCS	Flag
01111110	112/560 Bits	8 Bits	16 Bits	01111110

Fig. 1A -- U and S frame construction

First
Bit Sent

Flag	Address	Control	PID	Info.	FCS	Flag
01111110	112/560 Bits	8 Bits	8 Bits	N*8 Bits	16 Bits	01111110

Fig. 1B -- Information frame construction

Each field is made up of an integral number of octets (or bytes), and serves a specific function as outlined below.

2.2.1 Flag Field

[The flag field is one octet long. Since the flag is used to delimit frames, it occurs at both the beginning and end of each frame. Two frames may share one flag, which would denote the end of the first frame, and the start of the next frame. A flag consists of a zero followed by six ones followed by another zero, or 01111110 (7E hex). As a result of bit stuffing (see 2.2.6, below), this sequence is not allowed to occur anywhere else inside a complete frame.]

2.2.2 Address Field

[The address field is used to identify both the source of the frame and its destination. In addition, the address field contains the command/response information and facilities for level 2 repeater operation.]

The encoding of the address field is described in 2.2.13.

2.2.3 Control Field

The control field is used to identify the type of frame being passed and control several attributes of the level 2 connection. It is one octet in length, and its encoding is discussed in 2.3.2.1, below.

2.2.4 PID Field

The Protocol Identifier (PID) field shall appear in information frames (I and UI) only. It identifies what kind of layer 3 protocol, if any, is in use.

[The PID itself is not included as part of the octet count of the information field. The encoding of the PID is as follows:]

MSB LSB	
yy01yyyy	AX.25 layer 3 implemented.
yy10yyyy	AX.25 layer 3 implemented.
[11001100	Internet Protocol datagram layer 3 implemented.
11001101	Address resolution protocol layer 3 implemented.]
11110000	No layer 3 implemented.
11111111	Escape character. Next octet contains more Level 3 protocol information.

Where:

A y indicates all combinations used.

[Note:

All forms of yy11yyyy and yy00yyyy other than those listed above are reserved at this time for future level 3 protocols. The assignment of these formats is up to amateur agreement. It is recommended that the creators of level 3 protocols contact the ARRL Ad Hoc Committee on Digital Communications for suggested encodings.]

2.2.5 Information Field

The information field is used to convey user data from one end of the link to the other. I fields are allowed in only three tyes of frames: the I frame, the UI frame, and the FRMR frame. The I field can be up to 256 octets long, and shall contain an integral number of octets. These constraints apply prior to the insertion of zero bits as specified in 2.2.6, below. Any information in the I field shall be passed along the link transparently, except for the zero-bit insertion (see 2.2.6) necessary to prevent flags from accidentally appearing in the I field.

2.2.6 Bit Stuffing

In order to assure that the flag bit sequence mentioned above doesn't appear accidentially anywhere else in a frame, the sending station shall monitor the bit sequence for a group of five or more contiguous one bits. Any time five contiguous one bits are sent the sending station shall insert a zero bit after the fifth one bit. During frame reception, any time five contiguous one bits are received, a zero bit immediately following five one bits shall be discarded.

2.2.7 Frame-Check Sequence

The frame-check sequence (FCS) is a sixteen-bit number calculated by both the sender and receiver of a frame. It is used to insure that the frame was not corrupted by the medium used to get the frame from the sender to the receiver. It shall be calculated in accordance with ISO 3309 (HDLC) Recommendations.

2.2.8 Order of Bit Transmission

With the exception of the FCS field, all fields of an AX.25 frame shall be sent with each octet's least-significant bit first. The FCS shall be sent most-significant bit first.

2.2.9 Invalid Frames

Any frame consisting of less than 136 bits (including the opening and closing flags), not bounded by opening and closing flags, or not octet aligned (an integral number of octets), shall be considered an invalid frame by the link layer. See also 2.4.4.4, below.

2.2.10 Frame Abort

If a frame must be prematurely aborted, at least fifteen contiguous ones shall be sent with no bit stuffing added.

2.2.11 [Interframe Time Fill

Whenever it is necessary for a DXE to keep its transmitter on while not actually sending frames, the time between frames should be filled with contiguous flags.

2.2.12 Link Channel States

Not applicable.

2.2.13 Address-Field Encoding

The address field of all frames shall be encoded with both the destination and source amateur call signs for the frame. Except for the Secondary Station Identifier (SSID), the address field should be made up of upper-case alpha and numeric ASCII characters only. If level 2 amateur "repeaters" are to be used, their call signs shall also be in the address field.]

The HDLC address field is extended beyond one octet by assigning the least-significant bit of each octet to be an "extension bit". The extension bit of each octet is set to zero, to indicate the next octet contains more address information, or one, to indicate this is the last octet of the HDLC address field. To make room for this extension bit, the Amateur Radio call-sign information is shifted one bit left.

2.2.13.1 Nonrepeater Address-Field Encoding

If level 2 repeaters are not being used, the address field is encoded as shown in Fig. 2. The destination address is the call sign and SSID of the amateur radio station to which the frame is addressed, while the source address contains the amateur call sign and SSID of the station that sent the frame. These call signs are the call signs of the two ends of a level 2 AX.25 link <u>only</u>.

```
First
Octet Sent
-------------------------------------------------
|              Address Field of Frame           |
|-----------------------------------------------|
| Destination Address |      Source Address     |
|-----------------------------------------------|
|A1 A2 A3 A4 A5 A6 A7 | A8 A9 A10 A11 A12 A13 A14|
-------------------------------------------------
```

Fig. 2 -- Nonrepeater Address-Field Encoding

A1 through A14 are the fourteen octets that make up the two address subfields of the address field. The destination subaddress is seven octets long (A1 thru A7), and is sent first. This address sequence provides the receivers of frames time to check the destination address subfield to see if the frame is addressed to them while the rest of the frame is being received. The source address subfield is then sent in octets A8 through A14. Both of these subfields are encoded in the same manner, except that the last octet of the address field has the HDLC address extension bit set.

There is an octet at the end of each address subfield that contains the Secondary Station Identifier (SSID). The SSID subfield allows an Amateur Radio operator to have more than one packet-radio station operating under the same call sign. This is useful when an amateur wants to put up a repeater in addition to a regular station, for example. The C bits (see 2.4.1.2, below) and H bit (see 2.2.13.2, below) are also contained in this octet, along with two bits which are reserved for future use.

Fig. 3A Shows a typical AX.25 frame in the nonrepeater mode of operation.

Octet	ASCII	Bin.Data	Hex Data
Flag		01111110	7E
A1	K	10010110	96
A2	8	01110000	70
A3	M	10011010	9A
A4	M	10011010	9A
A5	O	10011110	9E
A6	space	01000000	40
A7	SSID	11100000	E0
A8	W	10101110	AE
A9	B	10000100	84
A10	4	01101000	68
A11	J	10010100	94
A12	F	10001100	8C
A13	I	10010010	92
A14	SSID	01100001	61
Control	I	00111110	3E
PID	none	11110000	F0
FCS	part 1	XXXXXXXX	HH
FCS	part 2	XXXXXXXX	HH
Flag		01111110	7E
Bit position		76543210	

Fig. 3A -- Nonrepeater AX.25 frame

The frame shown is an I frame, not going through a level 2 repeater, from WB4JFI (SSID=0) to K8MMO (SSID=0), with no level 3 protocol. The P/F bit is set; the receive sequence number (N(R)) is 1; the send sequence number (N(S)) is 7.

2.2.13.1.1 Destination Subfield Encoding

Fig. 3 shows how an amateur call sign is placed in the destination address subfield, occupying octets A1 thru A7.

Octet	ASCII	Bin.Data	Hex Data
A1	W	10101110	AE
A2	B	10000100	84
A3	4	01101000	68
A4	J	10010100	94
A5	F	10001100	8C
A6	I	10010010	92
A7	SSID	CRRSSID0	

Bit Position--> 76543210

Fig. 3 -- Destination Field Encoding

Where:

1. The top octet (A1) is the first octet sent, with bit 0 of each octet being the first bit sent, and bit 7 being the last bit sent.

2. The first (low-order or bit 0) bit of each octet is the HDLC address extension bit, which is set to zero on all but the last octet in the address field, where it is set to one.

3. The bits marked "R" are reserved bits. They may be used in an agreed-upon manner in individual networks. When not implemented, they should be set to one.

[4. The bit marked "C" is used as the command/response bit of an AX.25 frame, as outlined in 2.4.1.2 below.]

5. The characters of the call sign should be standard seven-bit ASCII (upper case only) placed in the leftmost seven bits of the octet to make room for the address extension bit. If the call sign contains fewer than six characters, it should be padded with ASCII spaces between the last call sign character and the SSID octet.

[6. The 0000 SSID is reserved for the first personal AX.25 station. This establishes one standard SSID for "normal" stations to use for the first station.]

2.2.13.2 Level 2 Repeater-Address Encoding

If a frame is to go through level 2 amateur packet repeater(s), there is an additional address subfield appended to the end of the address field. This additional subfield contains the call sign(s) of the repeater(s) to be used. This allows more than one repeater to share the same RF channel. If this subfield exists, the last octet of the source subfield has its address extension bit set to zero, indicating that more address-field data follows. The repeater-address subfield is encoded in the same manner as the destination and source address subfields, except for the most-significant bit in the last octet, called the "H" bit. The H bit is used to indicate whether a frame has been repeated or not.

[In order to provide some method of indicating when a frame has been repeated, the H bit is set to zero on frames going to a repeater. The repeater will set the H bit to one when the frame is retransmitted. Stations should monitor the H bit, and discard any frames going to the repeater (uplink frames), while operating through a repeater. Fig. 4 shows how the repeater-address subfield is encoded. Fig. 4A is an example of a complete frame after being repeated.]

Octet	ASCII	Bin.Data	Hex Data
A15	W	10101110	AE
A16	B	10000100	84
A17	4	01101000	68
A18	J	10010100	94
A19	F	10001100	8C
A20	I	10010010	92
A21	SSID	HRRSSID1	

Bit Order --> 76543210

Fig. 4 -- Repeater-address encoding

Where:

1. The top octet is the first octet sent, with bit 0 being sent first and bit 7 sent last of each octet.

2. As with the source and destination address subfields discussed above, bit 0 of each octet is the HDLC address extension bit, which is set to zero on all but the last address octet, where it is set to one.

3. The "R" bits are reserved in the same manner as in the source and destination subfields.

4. The "H" bit is the has-been-repeated bit. It is set to zero whenever a frame has not been repeated, and set to one by the repeater when the frame has been repeated.

Octet	ASCII	Bin.Data	Hex Data
Flag		01111110	7E
A1	K	10010110	96
A2	8	01110000	70
A3	M	10011010	9A
A4	M	10011010	9A
A5	O	10011110	9E
A6	space	01000000	40
A7	SSID	11100000	E0
A8	W	10101110	AE
A9	B	10000100	84
A10	4	01101000	68
A11	J	10010100	94
A12	F	10001100	8C
A13	I	10010010	92
A14	SSID	01100000	60
A15	W	10101110	AE
A16	B	10000100	84
A17	4	01101000	68
A18	J	10010100	94
A19	F	10001100	8C
A20	I	10010010	92
A21	SSID	11100011	E3
Control	I	00111110	3F
PID	none	11110000	F0
FCS	part 1	XXXXXXXX	HH
FCS	part 2	XXXXXXXX	HH
Flag		01111110	7E
Bit position		76543210	

Fig. 4A -- AX.25 frame in repeater mode

The above frame is the same as Fig. 3A, except for the addition of a repeater-address subfield (WB4JFI, SSID=1). The H bit is set, indicating this is from the output of the repeater.

2.2.13.3 [Multiple Repeater Operation

The link-layer AX.25 protocol allows operation through more than one repeater, creating a primitive frame routing mechanism. Up to eight repeaters may be used by extending the repeater-address subfield. When there is more than one repeater address, the repeater address immediately following the source address subfield will be considered the address of the first repeater of a multiple-repeater chain. As a frame progresses through a chain of repeaters, each successive repeater will set the H bit (has-been-repeated bit) in its SSID octet, indicating that the frame has been successfully repeated through it. No other changes to the frame are made (except for the necessary recalculation of the FCS). The destination station can determine the route the frame took to reach it by examining the address field.

The number of repeater addresses is variable. All but the last repeater address will have the address extension bits of all octets set to zero, as will all but the last octet (SSID octet) of the last repeater address. The last octet of the last repeater address will have the address extension bit set to one, indicating the end of the address field.

It should be noted that various timers (see 2.4.7, below) may have to be adjusted to accommodate the additional delays encountered when a frame must pass through a multiple-repeater chain, and the return acknowledgement must travel through the same path before reaching the source device.

It is anticipated that multiple-repeater operation is a temporary method of interconnecting stations over large distances until such time that a layer 3 protocol is in use. Once this layer 3 protocol becomes operational, repeater chaining should be phased out.

2.3 Elements of Procedure

2.3.1 The elements of procedure are defined in terms of actions that occur on receipt of frames.

2.3.2 Control-Field Formats and State Variables]

2.3.2.1 Control-Field Formats

The control field is responsible for identifying the type of frame being sent, and is also used to convey commands and responses from one end of the link to the other in order to maintain proper link control.

The control fields used in AX.25 use the CCITT X.25 control fields for balanced operation (LAPB), with an additional control field taken from ADCCP to allow connectionless and round-table operation.

There are three general types of AX.25 frames. They are the Information frame (I frame), the Supervisory frame (S frame), and the Unnumbered frame (U frame). Fig. 5 shows the basic format of the control field associated with these types of frames.

Control-Field Type	Control-Field Bits 7 6 5	4	3 2	1 0
I Frame	N(R)	P	N(S)	0
S Frame	N(R)	P/F	S S	0 1
U Frame	M M M	P/F	M M	1 1

Fig. 5 -- Control-field formats

Where:

1. Bit 0 is the first bit sent and bit 7 is the last bit sent of the control field.

[2. N(S) is the send sequence number (bit 1 is the LSB).

3. N(R) is the receive sequence number (bit 5 is the LSB).]

4. The "S" bits are the supervisory function bits, and their encoding is discussed in 2.3.4.2.

5. The "M" bits are the unnumbered frame modifier bits and their encoding is discussed in 2.3.4.3.

[6. The P/F bit is the Poll/Final bit. Its function is described in 2.3.3. The distinction between command and response, and therefore the distinction between P bit and F bit, is made by addressing rules discussed in 2.4.1.2.]

2.3.2.1.1 Information-Transfer Format

All I frames have bit 0 of the control field set to zero. N(S) is the sender´s send sequence number (the send sequence number of this frame). N(R) is the sender´s receive sequence number (the sequence number of the next expected received frame). These numbers are described in 2.3.2.4. In addition, the P/F bit is be used as described in 2.4.2.

2.3.2.1.2 Supervisory Format

Supervisory frames are denoted by having bit 0 of the control field set to one, and bit 1 of the control field set to zero. S frames provide supervisory link control such as acknowledging or requesting retransmission of I frames, and link-level window control. Since S frames do not have an information field, the sender´s send variable and the receiver´s receive variable are not incremented for S frames. In addition, the P/F bit is used as described in 2.4.2.

2.3.2.1.3 Unnumbered Format

Unnumbered frames are distinguished by having both bits 0 and 1 of the control field set to one. U frames are responsible for maintaining additional control over the link beyond what is accomplished with S frames. They are also responsible for establishing and terminating link connections. U frames also allow for the transmission and reception of information outside of the normal flow control. Some U frames may contain information and PID fields. The P/F bit is used as described in 2.4.2.

2.3.2.2 Control-Field Parameters

2.3.2.3 Sequence Numbers

Every AX.25 I frame shall be assigned, modulo 8, a sequential number from 0 to 7. This will allow up to seven outstanding I frames per level 2 connection at a time.

2.3.2.4 Frame Variables and Sequence Numbers

2.3.2.4.1 Send State Variable V(S)

The send state variable is a variable that is internal to the DXE and is never sent. It contains the next sequential number to be assigned to the next transmitted I frame. This variable is updated upon the transmission of each I frame.

2.3.2.4.2 Send Sequence Number N(S)

The send sequence number is found in the control field of all I frames. It contains the sequence number of the I frame being sent. Just prior to the transmission of the I frame, N(S) is updated to equal the send state variable.

2.3.2.4.3 Receive State Variable V(R)

The receive state variable is a variable that is internal to the DXE. It contains the sequence number of the next expected received I frame. This variable is updated upon the reception of an error-free I frame whose send sequence number equals the present received state variable value.

2.3.2.4.4 Received Sequence Number N(R)

The received sequence number is in both I and S frames. Prior to sending an I or S frame, this variable is updated to equal that of the received state variable, thus implictly acknowledging the proper reception of all I frames up to and including N(R)-1.

2.3.3 Functions of Poll/Final (P/F) Bit

[The P/F bit is used in all types of frames. It is used in a command (poll) mode to request an immediate reply to a frame. The reply to this poll is indicated by setting the response (final) bit in the appropriate frame. Only one outstanding poll condition per direction is allowed at a time. The procedure for P/F bit operation is described in 2.4.2.]

2.3.4 Control Field Coding for Commands and Responses

The following commands and responses, indicated by their control field encoding, are to be used by the DXE:

2.3.4.1 Information Command Frame Control Field

[The function of the information (I) command is to transfer across a data link sequentially numbered frames containing an information field.]

The information-frame control field is encoded as shown in Fig. 6. These frames are sequentially numbered by the N(S) subfield to maintain control of their passage over the link-layer connection.

Control Field Bits

7 6 5	4	3 2 1	0
N(R)	P	N(S)	0

Fig. 6 -- I frame control field

2.3.4.2 Supervisory Frame Control Field

The supervisory frame control fields are encoded as shown in Fig. 7.

Control Field Bits	7 6 5	4	3 2	1 0
Receive Ready RR	N(R)	P/F	0 0	0 1
Receive Not Ready RNR	N(R)	P/F	0 1	0 1
Reject REJ	N(R)	P/F	1 0	0 1

Fig. 7 -- S frame control fields

2.3.4.2.1 Receive Ready (RR) Command and Response

Receive Ready is used to do the following:

1. to indicate that the sender of the RR is now able to receive more I frames,

2. to acknowledge properly received I frames up to, and including N(R)-1, and

3. to clear a previously set busy condition created by an RNR command having been sent.

The status of the DXE at the other end of the link can be requested by sending a RR command frame with the P-bit set to one.

2.3.4.2.2 Receive Not Ready (RNR) Command and Response

Receive Not Ready is used to indicate to the sender of I frames that the receiving DXE is temporarily busy and cannot accept any more I frames. Frames up to N(R)-1 are acknowledged. Any I frames numbered N(R) and higher that might have been caught between states and not acknowledged when the RNR command was sent are not acknowledged.

The RNR condition can be cleared by the sending of a UA, RR, REJ, or SABM frame.

The status of the DXE at the other end of the link can be requested by sending a RNR command frame with the P bit set to one.

2.3.4.2.3 Reject (REJ) Command and Response

The reject frame is used to request retransmission of I frames starting with N(R). Any frames that were sent with a sequence number of N(R)-1 or less are acknowledged. Additional I frames may be appended to the retransmission of the N(R) frame if there are any.

Only one reject frame condition is allowed in each direction at a time. The reject condition is cleared by the proper reception of I frames up to the I frame that caused the reject condition to be initiated.

The status of the DXE at the other end of the link can be requested by sending a REJ command frame with the P bit set to one.

2.3.4.3 Unnumbered Frame Control Fields

Unnumbered frame control fields are either commands or responses.

Fig. 8 shows the layout of U frames implemented within this protocol.

Control Field	Type	Control Field Bits 7 6 5	4	3 2	1 0
Set Asynchronous Balanced Mode-SABM	Cmd	0 0 1	P	1 1	1 1
Disconnect-DISC	Cmd	0 1 0	P	0 0	1 1
Disconnected Mode DM	Res	0 0 0	F	1 1	1 1
Unnumbered Acknowledge-UA	Res	0 1 1	F	0 0	1 1
Frame Reject-FRMR	Res	1 0 0	F	0 1	1 1
Unnumbered Information-UI	Either	0 0 0	P/F	0 0	1 1

Fig. 8 -- U frame control fields

2.3.4.3.1 Set Asynchronous Balanced Mode (SABM) Command

The SABM command is used to place 2 DXEs in the asynchronous balanced mode. This is a balanced mode of operation known as LAPB where both devices are treated as equals.

Information fields are not allowed in SABM commands. Any outstanding I frames left when the SABM command is issued will remain unacknowledged.

[The DXE confirms reception and acceptance of a SABM command by sending a UA response frame at the earliest opportunity. If the DXE is not capable of accepting a SABM command, it should respond with a DM frame if possible.]

2.3.4.3.2 Disconnect (DISC) Command

The DISC command is used to terminate a link session between two stations. No information field is permitted in a DISC command frame.

Prior to acting on the DISC frame, the receiving DXE confirms acceptance of the DISC by issuing a UA response frame at its earliest opportunity. The DXE sending the DISC enters the disconnected state when it receives the UA response.]

Any unacknowledged I frames left when this command is acted upon will remain unacknowledged.

2.3.4.3.3 Frame Reject (FRMR) Response

2.3.4.3.3.1 The FRMR response frame is sent to report that the receiver of a frame cannot successfully process that frame and that the error condition is not correctable by sending the offending frame again. Typically this condition will appear when a frame without an FCS error has been received with one of the following conditions:

1. The reception of an invalid or not implemented command or response frame.

2. The reception of an I frame whose information field exceeds the agreed-upon length. (See 2.4.7.3, below.)

3. The reception of an improper N(R). This usually happens when the N(R) frame has already been sent and acknowledged, or when N(R) is out of sequence with what was expected.

4. The reception of a frame with an information field where one is not allowed, or the reception of a U or S frame whose length is incorrect. Bits W and Y described in 2.3.4.3.3.2 should both be set to one to indicate this condition.

[5. The reception of a supervisory frame with the F bit set to one, except during a timer recovery condition (see 2.4.4.9), or except as a reply to a command frame sent with the P bit set to one. Bit W (described in 2.3.4.3.3.2) should be set to one.

6. The reception of an unexpected UA or DM response frame. Bit W should be set to one.

7. The reception of a frame with an invalid N(S). Bit W should be set to one.

An invalid N(R) is defined as one which points to an I frame that previously has been transmitted and acknowledged, or an I frame which has not been transmitted and is not the next sequential I frame pending transmission.

An invalid N(S) is defined as an N(S) that is equal to the last transmitted N(R)+k and is equal to the received state variable V(R), where k is the maximum number of outstanding information frames as defined in 2.4.7.4 below.

An invalid or not implemented command or response is defined as a frame with a control field that is unknown to the receiver of this frame.

2.3.4.3.3.2 When a FRMR frame is sent, an information field is added to the frame that contains additional information indicating where the problem occurred. This information field is three octets long and is shown in Fig. 9.]

```
-----------------------------------------------------
|              Information Field Bits               |
| 2 2 2 2 1 1 1 1 1 1 1 1 1 1                       |
| 3 2 1 0 9 8 7 6 5 4 3 2 1 0 9 8 7 6 5 4 3 2 1 0|
|---------------------------------------------------|
| 0 0 0 0|Z|Y|X|W| V(R)|C| V(S)|0| Rejected Frame|
|        | | | | |     |R|     | | Control Field |
-----------------------------------------------------
```

Fig. 9 -- FRMR frame information field

Where:

[1. The rejected frame control field carries the control field of the frame that caused the reject condition. It is in bits 0-7 of the information field.

2. V(S) is the current send state variable of the device reporting the rejection (bit 9 is the low bit).

3. The CR bit is set to zero to indicate the rejected frame was a command, or one if it was a response.

4. V(R) is the current receive state variable of the device reporting rejection (bit 13 is the low bit).]

5. If W is set to 1, the control field received was invalid or not implemented.

6. If X is set to 1, the frame that caused the reject condition was considered invalid because it was a U or S frame that had an information field that is not allowed. Bit W must be set to 1 in addition to the X bit.

7. If Y is set to 1, the information field of a received frame exceeded the maximum allowed under this recommendation in 2.4.7.3, below.

[8. If Z is set to 1, the control field received and returned in bits 1 to 8 contained an invalid N(R).

9. Bits 8, and 20 to 23 are set to 0.]

2.3.4.3.4 Unnumbered Acknowledge (UA) Response

The UA response frame is sent to acknowledge the reception and acceptance of a SABM or DISC command frame. A received command is not actually processed until the UA response frame is sent. Information fields are not permitted in a UA frame.

2.3.4.3.5 Disconnected Mode (DM) Response

[The disconnected mode response is sent whenever a DXE receives a frame other than a SABM or UI frame while in a disconnected mode. It is also sent to request a set mode command, or to indicate it cannot accept a connection at the moment. The DM response does not have an information field.

Whenever a SABM frame is received, and it is determined that a connection is not possible, a DM frame shall be sent. This will indicate that the called station cannot accept a connection at that time.

While a DXE is in the disconnected mode, it will respond to any command other than a SABM or UI frame with a DM response with the P/F bit set to 1.

2.3.4.3.6 Unnumbered Information (UI) Frame

The Unnumbered Information frame contains PID and information fields and is used to pass information along the link outside the normal information controls. This allows information fields to go back and forth on the link bypassing flow control. Since these frames are <u>not</u> acknowledgeable, if one gets obliterated, there is no way to recover it. A received UI frame with the P bit set shall cause a response to be transmitted. This response shall be a DM frame when in the disconnected state or a RR (or RNR, if appropriate) frame in the information transfer state.]

2.3.5 Link Error Reporting and Recovery

There are several link-layer errors that are recoverable without terminating the connection. These error situations may occur as a result of malfunctions within the DXE, or if transmission errors occur.

2.3.5.1 DXE Busy Condition

When a DXE becomes temporarily unable to receive I frames, such as when receive buffers are full, it will send a Receive Not Ready (RNR) frame. This informs the other DXE that this DXE cannot handle any more I frames at the moment. This condition is usually cleared by the sending of a UA, RR, REJ, or SABM command frame.

2.3.5.2 Send Sequence Number Error

If the send sequence number, N(S), of an otherwise error-free received I frame does not match the receive state variable, V(R), a send sequence error has occured, and the information field will be discarded. The receiver will not acknowledge this frame, or any other I frames, until N(S) matches V(R).

The control field of the erroneous I frame(s) will be accepted so that link supervisory functions such as checking the P/F bit can still be performed. Because of this updating, the retransmitted I frame may have an updated P bit and N(R).

2.3.5.3 Reject (REJ) Recovery

REJ is used to request a retransmission of I frames following the detection of a N(S) sequence error. Only one outstanding "sent REJ" condition is allowed at a time. This condition is cleared when the requested I frame has been received.

A DXE receiving the REJ command will clear the condition by re-sending all outstanding I frames (up to the window size), starting with the one indicated in N(R) of of the REJ command frame.

2.3.5.4 Time-out Error Recovery

2.3.5.4.1 [T1 Timer Recovery

If a DXE, due to a transmission error, does not receive (or receives and discards) a single I frame or the last I frame in a sequence of I frames, it will not detect a send-sequence-number error, and therefore will not transmit a REJ. The DXE which transmitted the unacknowledged I frame(s) shall, following the completion of time-out period T1, take appropriate recovery action to determine when I frame retransmission should begin as described in 2.4.4.9, below. This condition is cleared by the reception of an acknowledgement for the sent frame(s), or by the link being reset. See 2.4.6.

2.3.5.4.2 Timer T3 Recovery

Timer T3 is used to assure the link is still functional during periods of low information transfer. Whenever T1 is not running (no outstanding I frames), T3 is used to periodically poll the other DXE of a link. When T3 times out, a RR or RNR frame is transmitted as a command and with the P bit set. The waiting acknowledgement procedure (2.4.4.9, below) is then executed.]

2.3.5.5 Invalid Frame or FCS Error

If an invalid frame is received, or a frame is received with an FCS error, that frame will be discarded with no action taken.

2.3.5.6 Frame Rejection Condition

[A frame rejection condition occurs when an otherwise error-free frame has been received with one of the conditions listed in 2.3.4.3.3 above.]

Once a rejection error occurs, no more I frames are accepted (except for the examination of the P/F bit) until the error is resolved. The error condition is reported to the other DXE by sending a FRMR response frame. See 2.4.5.

2.4 Description of AX.25 Procedures

The following describes the procedures used to setup, use, and disconnect a balanced link between two DXE stations.

2.4.1 Address Field Operation

2.4.1.1 Address Information

All transmitted frames shall have address fields conforming to 2.2.13, above. All frames shall have both the destination device and the source device addresses in the address field, with the destination address coming first. This allows many links to share the same RF channel. The destination address is always the address of the station(s) to receive the frame, while the source address contains the address of the device that sent the frame.

The destination address can be a group name or club call sign if point-to-multipoint operation is allowed. Operation with destination addresses other than actual amateur call signs is a subject for further study.

2.4.1.2 [Command/Response Procedure

AX.25 Version 2.0 has implemented the command/response information in the address field. In order to maintain compatibility with previous versions of AX.25, the command/response information is conveyed using two bits.

An upward-compatible AX.25 DXE can determine whether it is communicating with a DXE using an older version of this protocol by testing the command/response bit information located in bit 7 of the SSID octets of both the destination and source address subfields. If both C bits are set to zero, the device is using the older protocol. The newer version of the protocol always has one of these two bits set to one and the other set to zero, depending on whether the frame is a command or a response.

The command/response information is encoded into the address field as shown in Fig. 10.

Frame Type	Dest. SSID C-Bit	Source SSID C-Bit
Previous versions	0	0
Command (V.2.0)	1	0
Response (V.2.0)	0	1
Previous versions	1	1

Fig. 10 -- Command/Response encoding

Since all frames are considered either commands or responses, a device shall always have one of the bits set to one, and the other bit set to zero.

The use of the command/response information in AX.25 allows S frames to be either commands or responses. This aids maintainance of proper control over the link during the information transfer state.

2.4.2 P/F Bit Procedures

The next response frame returned by the DXE to a SABM or DISC command with the P bit set to 1 will be a UA or DM response with the F bit set to 1.

The next response frame returned to an I frame with the P bit set to 1, received during the information transfer state, will be a RR, RNR, or REJ response with the F bit set to 1.

The next response frame returned to a supervisory command frame with the P bit set to 1, received during the information transfer state, will be a RR, RNR, or REJ response frame with the F bit set to 1.

The next response frame returned to a S or I command frame with the P bit set to 1, received in the disconnected state, will be a DM response frame with the F bit set to 1.

The P bit is used in conjunction with the time-out recovery condition discussed in 2.3.5.4, above.

When not used, the P/F bit is set to zero.]

2.4.3 Procedures For Link Set-Up and Disconnection

2.4.3.1 LAPB Link Connection Establishment

When one DXE wishes to connect to another DXE, it will send a SABM command frame to that device and start timer (T1). If the other DXE is there and able to connect, it will respond with a UA response frame, and reset both of its internal state variables (V(S) and V(R)). The reception of the UA response frame at the other end will cause the DXE requesting the connection to cancel the T1 timer and set its internal state variables to 0.

[If the other DXE doesn´t respond before T1 times out, the device requesting the connection will re-send the SABM frame, and start T1 running again. The DXE should continue to try to establish a connection until it has tried unsuccessfully N2 times. N2 is defined in 2.4.7.2, below.

If, upon reception of a SABM command, the DXE decides that it cannot enter the indicated state, it should send a DM frame.

When receiving a DM response, the DXE sending the SABM should cancel its T1 timer, and not enter the information-transfer state.

The DXE sending a SABM command will ignore and discard any frames except SABM, DISC, UA, and DM frames from the other DXE.

Frames other than UA and DM in response to a received SABM will be sent only after the link is set up and if no outstanding SABM exists.

2.4.3.2 Information-Transfer Phase

After establishing a link connection, the DXE will enter the information-transfer state. In this state, the DXE will accept and transmit I and S frames according to the procedure outlined in 2.4.4, below.

When receiving a SABM command while in the information-transfer state, the DXE will follow the resetting procedure outlined in 2.4.6 below.]

2.4.3.3 Link Disconnection

2.4.3.3.1 While in the information-transfer state, either DXE may indicate a request to disconnect the link by transmitting a DISC command frame and starting timer T1 (see 2.4.7).

2.4.3.3.2 A DXE, upon receiving a valid DISC command, shall send a UA response frame and enter the disconnected state. A DXE, upon receiving a UA or DM response to a sent DISC command, shall cancel timer T1, and enter the disconnected state.

2.4.3.3.3 [If a UA or DM response is not correctly received before T1 times out, the DISC frame should be sent again and T1 restarted. If this happens N2 times, the DXE should enter the disconnected state.]

2.4.3.4 Disconnected State

2.4.3.4.1 [A DXE in the disconnected state shall monitor received commands and react upon the reception of a SABM as described in 2.4.3.1 above and will transmit a DM frame in response to a DISC command.]

2.4.3.4.2 In the disconnected state, a DXE may initiate a link set-up as outlined in connection establishment above (2.4.3.1). It may also respond to the reception of a SABM and establish a connection, or it may ignore the SABM and send a DM instead.

2.4.3.4.3 [Any DXE receiving a command frame other than a SABM or UI frame with the P bit set to one should respond with a DM frame with the F bit set to one. The offending frame should be ignored.

2.4.3.4.4 When the DXE enters the disconnected state after an error condition or if an internal error has resulted in the DXE being in the disconnected state, the DXE should indicate this by sending a DM response rather than a DISC frame and follow the link disconnection procedure outlined in 2.4.3.3.3, above. The DXE may then try to re-establish the link using the link set-up procedure outlined in 2.4.3.1, above.]

2.4.3.5 Collision Recovery

2.4.3.5.1 Collisions in a Half-Duplex Environment

Collisions of frames in a half-duplex environment are taken care of by the retry nature of the T1 timer and retransmission count variable. No other special action needs to be taken.

2.4.3.5.2 Collisions of Unnumbered Commands

[If sent and received SABM or DISC command frames are the same, both DXEs should send a UA response at the earliest opportunity, and both devices should enter the indicated state.

If sent and received SABM or DISC commands are different, both DXEs should enter the disconnected state and transmit a DM frame at the earliest opportunity.]

2.4.3.5.3 Collision of a DM with a SABM or DISC

When an unsolicited DM response frame is sent, a collision between it and a SABM or DISC may occur. In order to prevent this DM from being misinterpreted, all unsolicited DM frames should be transmitted with the F bit set to zero. All SABM and DISC frames should be sent with the P bit set to one. This will prevent any confusion when a DM frame is received.

2.4.3.6 Connectionless Operation

In Amateur Radio, there is an additional type of operation that is not feasable using level 2 connections. This operation is the round table, where several amateurs may be engaged in one conversation. This type of operation cannot be accommodated by AX.25 link-layer connections.

The way round-table activity is implemented is technically outside the AX.25 connection, but still using the AX.25 frame structure.

AX.25 uses a special frame for this operation, called the Unnumbered Information (UI) frame. When this type of operation is used, the destination address should have a code word installed in it to prevent the users of that particular round table from seeing all frames going through the shared RF medium. An example of this is if a group of amateurs are in a round-table discussion about packet radio, they could put PACKET in the destination address, so they would receive frames only from others in the same discussion. An added advantage of the use of AX.25 in this manner is that the source of each frame is in the source address subfield, so software could be written to automatically display who is making what comments.

Since this mode is connectionless, there will be no requests for retransmissions of bad frames. Collisions will also occur, with the potential of losing the frames that collided.

2.4.4 Procedures for Information Transfer

Once a connection has been established, as outlined above, both devices are able to accept I, S, and U frames.

2.4.4.1 Sending I Frames

[Whenever a DXE has an I frame to transmit, it will send the I frame with N(S) of the control field equal to its current send state variable V(S). Once the I frame is sent, the send state variable is incremented by one. If timer T1 is not running, it should be started. If timer T1 is running, it should be restarted.]

The DXE should not transmit any more I frames if its send state variable equals the last received N(R) from the other side of the link plus seven. If it were to send more I frames, the flow control window would be exceeded, and errors could result.

If a DXE is in a busy condition, it may still send I frames as long as the other device is not also busy.

If a DXE is in the frame-rejection mode, it will stop sending I frames.

2.4.4.2 Receiving I Frames

2.4.4.2.1 If a DXE receives a valid I frame (one with a correct FCS and whose send sequence number equals the receiver's receive state variable) and is not in the busy condition, it will accept the received I frame, increment its receive state variable, and act in one of the following manners:

1. If it has an I frame to send, that I frame may be sent with the transmitted N(R) equal to its receive state variable V(R) (thus acknowledging the received frame). Alternately, the device may send a RR frame with N(R) equal to V(R), and then send the I frame.

[2. If there are no outstanding I frames, the receiving device will send a RR frame with N(R) equal to V(R). The receiving DXE may wait a small period of time before sending the RR frame to be sure additional I frames are not being transmitted.]

2.4.4.2.2 If the DXE is in a busy condition, it may ignore any received I frames without reporting this condition other than repeating the indication of the busy condition.

If a busy condition exists, the DXE receiving the busy condition indication should poll the sender of the busy indication periodically until the busy condition disappears.

[A DXE may poll the busy DXE periodically with RR or RNR frames with the P bit set to one.]

The reception of I frames that contain zero-length information fields shall be reported to the next level but no information field will be transferred.

2.4.4.3 Reception of Out of Sequence Frames

When an I frame is received with a correct FCS, but its send sequence number, N(S), does not match the current receiver's receive state variable, the frame should be discarded. A REJ frame shall be sent with a receive sequence number equal to one higher (modulo 8) than the last correctly received I frame if an uncleared N(S) sequence error condition has not been previously established. The received state variable and poll bit of the discarded frame should be checked and acted upon, if necessary, before discarding the frame.

2.4.4.4 Reception of Incorrect Frames

When a DXE receives a frame with an incorrect FCS, an invalid frame, or a frame with an improper address, that frame shall be discarded.

2.4.4.5 Receiving Acknowledgement

Whenever an I or S frame is correctly received, even in a busy condition, the N(R) of the received frame should be checked to see if it includes an acknowldegment of outstanding sent I frames. The T1 timer should be cancelled if the received frame actually acknowledges previously unacknowledged frames. If the T1 timer is cancelled and there are still some frames that have been sent that are not acknowledged, T1 should be started again. If the T1 timer runs out before an acknowledgement is received, the device should proceed to the retransmission procedure in 2.4.4.9.

2.4.4.6 Receiving Reject

Upon receiving a REJ frame, the transmitting DXE will set its send state variable to the same value as the REJ frame's received sequence number in the control field. The DXE will then retransmit any I frame(s) outstanding at the next available opportunity conforming to the following:

1. If the DXE is not transmitting at the time, and the channel is open, the device may commence to retransmit the I frame(s) immediately.

[2. If the DXE is operating on a full-duplex channel transmitting a UI or S frame when it receives a REJ frame, it may finish sending the UI or S frame and then retransmit the I frame(s).]

3. If the DXE is operating in a full-duplex channel transmitting another I frame when it receives a REJ frame, it may abort the I frame it was sending and start retransmission of the requested I frames immediately.

4. The DXE may send just the one I frame outstanding, or it may send more than the one indicated if more I frames followed the first one not acknowledged, provided the total to be sent does not exceed the flow-control window (7 frames).

If the DXE recives a REJ frame with the poll bit set, it should respond with either a RR or RNR frame with the final bit set before retransmitting the outstanding I frame(s).

2.4.4.7 Receiving a RNR Frame

[Whenever a DXE receives a RNR frame, it shall stop transmission of I frames until the busy condition has been cleared. If timer T1 runs out after the RNR was received, the waiting acknowledgement procedure listed in 2.4.4.9, below, should be performed. The poll bit may be used in conjunction with S frames to test for a change in the condition of the busied-out DXE.]

2.4.4.8 Sending a Busy Indication

Whenever a DXE enters a busy condition, it will indicate this by sending a RNR response at the next opportunity. While the DXE is in the busy condition, it may receive and process S frames, and if a received S frame has the P bit set to one, the DXE should send a RNR frame with the F bit set to one at the next possible opportunity. To clear the busy condition, the DXE should send either a RR or REJ frame with the received sequence number equal to the current receive state variable, depending on whether the last received I frame was properly received or not.

2.4.4.9 Waiting Acknowledgement

[If timer T1 runs out waiting the acknowledgement from the other DXE for an I frame transmitted, the DXE will restart timer T1 and tramsmit an appropriate supervisory command frame (RR or RNR) with the P bit set. If the DXE receives correctly a supervisory response frame with the F bit set and with an N(R) within the range from the last N(R) received to the last N(S) sent plus one, the DXE will restart timer T1 and will set its send state variable V(S) to the received N(R). It may then resume with I frame transmission or retransmission, as appropriate. If, on the other hand, the DXE receives correctly a supervisory response frame with the F bit not set, or an I frame or supervisory command frame, and with an N(R) within the range from the last N(R) received to the last N(S) sent plus one, the DTE will not restart timer T1, but will use the received N(R) as an indication of acknowledgement of transmitted I frames up to and including I frame numbered N(R)-1.

If timer T1 runs out before a supervisory response frame with the F bit set is received, the DXE will retransmit an appropriate supervisory command frame (RR or RNR) with the P bit set. After N2 attempts to get a supervisory response frame with the F bit set from the other DXE, the DXE will initiate a link resetting procedure as described in 2.4.6, below.]

2.4.5 Frame Rejection Conditions

[A DXE shall initiate the frame-reset procedure when a frame is received with the correct FCS and address field during the information-transfer state with one or more of the conditions in 2.3.4.3.3, above.

Under these conditions, the DXE will ask the other DXE to reset the link by transmitting a FRMR response as outlined in 2.4.6.3, below.]

After sending the FRMR frame, the sending DXE will enter the frame reject condition. This condition is cleared when the DXE that sent the FRMR frame receives a SABM or DISC command, or a DM response frame. Any other command received while the DXE is in the frame reject state will cause another FRMR to be sent out with the same information field as originally sent.

[In the frame rejection condition, additional I frames will not be transmitted, and received I frames and S frames will be discarded by the DXE.]

The DXE that sent the FRMR frame shall start the T1 timer when the FRMR is sent. If no SABM or DISC frame is received before the timer runs out, the FRMR frame shall be retransmitted, and the T1 timer restarted as described in the waiting acknowledgement section (2.4.4.9) above. If the FRMR is sent N2 times without success, the link shall be reset.

2.4.6 Resetting Procedure

2.4.6.1 The resetting procedure is used to initialize both directions of data flow after a nonrecoverable error has occured. This resetting procedure is used in the information-transfer state of an AX.25 link only.

2.4.6.2 [A DXE shall initiate a reset procedure whenever it receives an unexpected UA response frame or an unsolicited response frame with the F bit set to one. A DXE may also initiate the reset procedure upon receipt of a FRMR frame. Alternatively, the DXE may respond to a FRMR by terminating the connection with a DISC frame.]

2.4.6.3 [A DXE shall reset the link by sending a SABM frame and starting timer T1. Upon receiving a SABM frame from the DXE previously connected to, the receiver of a SABM frame should send a UA frame back at the earliest opportunity, set its send and receive state variables, V(S) and V(R), to zero and stop T1 unless it has sent a SABM or DISC itself. If the UA is correctly received by the initial DXE, it resets its send and receive state variables, V(S) and V(R), and stops timer T1. Any busy condition that previously existed will also be cleared.

If a DM response is received, the DXE will enter the disconnected state and stop timer T1. If timer T1 runs out before a UA or DM response frame is recieved, the SABM will be retransmitted and timer T1 restarted. If timer T1 runs out N2 times, the DXE will enter the disconnected state, and any previously existing link conditions will be cleared.]

Other commands or responses received by the DXE before completion of the reset procedure will be discarded.

2.4.6.4 One DXE may request that the other DXE reset the link by sending a DM response frame. After the DM frame is sent, the sending DXE will then enter the disconnected state.

2.4.7 List of System Defined Parameters

2.4.7.1 Timers

[To maintain the integrity of the AX.25 level 2 connection, use of these timers is recommended.]

2.4.7.1.1 Acknowledgement Timer T1

The first timer, T1, is used to make sure a DXE doesn't wait forever for a response to a frame it sends. This timer cannot be expressed in absolute time, since the time required to send frames varies greatly with the signaling rate used at level 1. T1 should take at least twice the amount of time it would take to send a maximum length frame to the other DXE, and get the proper response frame back from the other DXE. This would allow time for the other DXE to do some processing before responding.

[If level 2 repeaters are to be used, the value of T1 should be adjusted according to the number of repeaters the frame is being transferred through.]

2.4.7.1.2 [Response Delay Timer T2

The second timer, T2, may be implemented by the DXE to specify a maximum amount of delay to be introduced between the time an I frame is received, and the time the resulting response frame is sent. This delay may be introduced to allow a receiving DXE to wait a short period of time to determine if there is more than one frame being sent to it. If more frames are received, the DXE can acknowledge them at once (up to seven), rather than acknowledge each individual frame. The use of timer T2 is not mandatory, but is recommended to improve channel efficiency. Note that, on full-duplex channels, acknowledgements should not be delayed beyond k/2 frames to achieve maximum throughput. The k parameter is defined in 2.4.7.4, below.

2.4.7.1.3 Inactive Link Timer T3

The third timer, T3, is used whenever T1 isn´t running to maintain link integrity. It is recommended that whenever there are no outstanding unacknowledged I frames or P-bit frames (during the information-transfer state), a RR or RNR frame with the P bit set to one be sent every T3 time units to query the status of the other DXE. The period of T3 is locally defined, and depends greatly on level 1 operation. T3 should be greater than T1, and may be very large on channels of high integrity.]

2.4.7.2 Maximum Number of Retries (N2)

The maximum number of retries is used in conjunction with the T1 timer.

2.4.7.3 Maximum Number of Octets in an I Field (N1)

The maximum number of octets allowed in the I field will be 256. There shall also be an integral number of octets.

2.4.7.4 Maximum Number of I Frames Outstanding (k)

The maximum number of outstanding I frames at a time is seven.

Appendix A -- Glossary

Note: This appendix is not a part of the protocol.

ADCCP -- Advanced data communication control procedure, a bit-oriented link-level protocol developed by ANSI.

Address field -- The octets within an HDLC frame containing the identities of the sending and receiving stations.

AMRAD -- Amateur Radio Research and Development Corporation, a nonprofit organization involved in packet-radio development. (P.O. Drawer 6148, McLean, VA 22106.)

AMSAT -- The Radio Amateur Satellite Corporation, a nonprofit organization involved in packet radio via OSCAR satellites. (P.O. Box 27, Washington, DC 20044.)

ANSI -- American National Standards Institute. (1430 Broadway, New York, NY 10018.)

Balanced -- A relationship where two stations communicate with one another as equals; that is, neither is primary (master) or secondary (slave).

Bit -- Binary digit.

CCITT -- International Telegraph and Telephone Consultative Committee, a part of the International Telecommunication Union.

Collision -- A condition when two or more transmissions occur at the same time and cause interference to the intended receiver(s).

Connection -- At the link layer, logical coupling of two packet-radio stations for information-transfer and control purposes.

Control field -- An 8-bit pattern in an HDLC frame containing commands or responses, and sequence numbers.

CRC -- Cyclic Redundancy Check, a mathematical operation in which the results are sent with a transmission block to enable receiving stations to check the integrity of the data. (Reference ISO 3309 Annex.)

DCE -- Data Circuit-Terminating Equipment, a master station in unbalanced mode at the link layer. Compare DTE and DXE.

Domain -- In packet radio, the combination of a frequency and a geographical service area.

DTE -- Data Terminal Equipment, a slave station in unbalanced mode at the link layer. Compare DCE and DXE.

DXE -- Data Switching Equipment, a peer (neither master or slave) station in balanced mode at the link layer. Compare DCE and DTE.

Destination -- The station that is the intended receiver of the frame sent over a radio link, either directly or via a repeater.

FCS -- Frame Check Sequence. See CRC.

Field -- In link-layer packet radio, a subdivision of a frame, consisting of one or more octets.

Flag -- In HDLC, a bit pattern (01111110) used to initiate and terminate a frame.

Flow control -- Measures to restrict the data transmission rate to one which can be accommodated by the receiver.

Frame -- The data structure of the high-level data link control procedure (HDLC).

Full duplex -- A physical or logical connection between two points over which data may travel in both directions simultaneously.

Half duplex -- A physical or logical connection between two points over which data may travel in both directions alternately (one way at a time).

Hex -- Hexadecimal, a base-16 number system that uses the symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F.

HDLC -- High-level data link control procedures, as specified in ISO 3309 and other international standards.

Information field -- Any sequence of bits which, when used, contains the intelligence to be conveyed in a frame.

ISO -- International Organization for Standardization.

ISO 3309 -- An international standard entitled, "Data communication -- High-level data link control procedures -- Frame structure."

LAP -- Link Access Procedure, a link-layer protocol for X.25 unbalanced-mode communications between DTE and DCE.

LAPB -- Link Access Procedure, Balanced, a link-layer protocol for X.25 balanced-mode communications between peer stations.

Layer -- In communications protocols, one of the strata or levels in a reference model. For example, the ISO open systems interconnection (OSI) reference model has seven functional layers.

Level -- See layer.

LSB -- Least-significant bit.

MSB -- Most-significant bit.

Octet -- A group of eight bits.

OSI -- Open systems interconnection, a communications protocol reference model developed by the International Organization for Standardization (ISO).

Packet Radio -- A digital communications technique involving radio transmission of short bursts (frames) of data containing addressing, control and error-checking information in the transmission.

PID -- Protocol Identifier -- Within AX.25 link-layer protocol, an octet whose bit patterns signify the specific network-layer protocol in use, if any.

PPRS -- Pacific Packet Radio Society. (c/o Hank Magnuski, KA6M, 311 Standord Avenue, Menlo Park, CA 94025.)

Primary -- The master station in a master-slave relationship; the master maintains control and is able to perform actions that the slave cannot. Compare secondary.

Protocol -- A formal set of rules and procedures for the exchange of information within a network.

RATS -- Radio Amateur Telecommunication Society. (c/o J. Gordon Beattie Jr., N2DSY, 45 Union Ave., Little Falls, NJ 07424.)

Repeater -- In packet radio, an Amateur Radio station that receives frames, tests their integrity by performing a cyclic redundancy check, and (if the CRC is good) retransmits the frame without readdressing.

Secondary -- The slave in a master-slave relationship. Compare primary.

SLAPR -- St. Louis Amateur Packet Radio. (c/o Pete Eaton, WB9FLW, 35 Norspur, Route 4, Edwardsville, IL 62025.)

Source -- The station transmitting the frame over a direct radio link or via a repeater.

TAPR -- Tucson Amateur Packet Radio Corporation, a nonprofit organization involved in packet-radio development. (P.O. Box 22888, Tucson, AZ 85734.)

VADCG -- Vancouver Amateur Digital Communications Group. (c/o Doug Lockhart, VE7APU, 9531 Odlin Road, Richmond, BC, V6X 1E1, Canada.)

Window -- In link-layer packet radio, the range of frame numbers within the control field used to set the maximum number of frames the sender may transmit before it receives an acknowledgement from the receiver.

X.25 -- A CCITT Recommendation entitled, "Interface between Data Terminal Equipment (DTE) and Data Circuit-Terminating Equipment (DCE) for Terminals Operating in the Packet Mode on Public Data Networks."

Appendix B — References

Note: This appendix is not a part of the protocol.

American Telephone and Telegraph Company, "Operations Systems Network Communications Protocol Specification BX.25 - Issue 2."

ANSI X3.66, "Advanced Data Communication Control Procedure," (ADCCP).

CCITT Recommendation X.25, "Interface between Data Terminal Equipment (DTE) and Data-Circuit Terminating Equipment (DCE) for Terminals Operating in the Packet Mode on Public Data Networks."

ISO 3309, "Data communication -- High-level data link control procedures -- Frame structure."

ISO 7205, "Reference Model of Open Systems Architecture."

ISO 7776, "Information Processing Systems - Data Communications - 2nd DP 7776 REVISED - Description of the 1984 X.25 LAPB - Compatible DTE Data Link Procedures."

Appendix C — Implementation Notes

Note: This appendix is not a part of the protocol.

Several implementations of packet-radio devices existed prior to the publication of this document. In order to maintain full compatibility with those devices, implementors of new AX.25 systems may wish to consider the following points.

The use of the P/F bit in conjuction with the command/response bits, described in section 2.3.3 and in the state tables of appendix A, was not standardized until the publication of this document. AX.25 devices produced prior to the publication of this standard may handle the P/F bit in a different manner and the C bits not at all. No known implementation of AX.25 that existed before this standard uses the C bits in any way. Since this standard requires that the C bits always be complements of one another, the presence of an AX.25 device of nonstandard protocol can be detected by examining these bits and determining that they are both the same (that is, both 0 or both 1).

Upon finding that the device at the other end of the link is non-standard, the standard AX.25 DXE should relax the requirements on its use of the P/F bit. Specifically, the other DXE may or may not reply to a poll (P bit equals 1). If it does reply, the F bit may or may not be set. The question of whether or not a given frame is a command or a response is somewhat confused without the C bits, and the standard DXE should assume that, in the absence of proper C bit content, the other DXE is incapable of proper P/F bit operation.

Appendix D -- State Tables

State	I with Poll	I without P	RR with Poll	RR without P	REJ with Poll	REJ without p	RNR with Poll	RNR without p	SABM either	DISC either
S1 Disconnected	DM		DM		DM		DM		UA,S5*	DM**
S2 Link Setup									UA,S5*	DM,S1
S3 Frame Reject	FRMR		FRMR		FRMR		FRMR		UA,S5*	UA,S1
S4 Disconnect Rqst	DM,S1		DM,S1		DM,S1		DM,S1		DM,S1	UA,S1
S5 Information Xfr	RR	I	RR	I	RR	I	RR,S9	S9	UA	UA,S1
S6 REJ Frame Sent	RR,S5	I,S5	RR	I	RR	I	RR,S15	S15	UA,S5	UA,S1
S7 Waiting Acknow.	RR	I	RR	I	RR	I	RR,S12	S12	UA,S5	UA,S1
S8 Device Busy	RNR	RNR	RNR	I	RNR	I	RNR,S10	S10	UA	UA,S1
S9 Remote Device Busy	RR	RR	RR,S5	I,S5	RR,S5	I,S5	RR		UA,S5	UA,S1
S10 Both Devices Busy	RNR	RNR	RNR,S8	I,S8	RNR,S8	I,S8	RNR		UA,S8	UA,S1
S11 Waiting Acknow. and Device Busy	RNR	RNR	RNR	I	RNR	I	RNR,S13	S13	UA,S8	UA,S1
S12 Waiting Acknow. and Remote Busy	RR	RR	RR,S7	I,S7	RR,S7	I,S7	RR		UA,S5	UA,S1
S13 Waiting Acknow. Both Devices Busy	RNR	RNR	RNR,S11	I,S11	RNR,S11	I,S11	RNR		UA,S8	UA,S1
S14 REJ Sent and and Device Busy	RNR	RNR	RNR	I	RNR	I	RNR,S16	S16	UA,S8	UA,S1
S15 REJ Sent and Remote Busy	RR,S9	RR,S9	RR,S6	I,S6	RR,S6	I,S6	RR		UA,S5	UA,S1
S16 REJ Sent and Both Devices Busy	RNR	RNR	RNR,S14	I,S14	RNR,S14	I,S14	RNR		UA,S5	UA,S1

* DM,S1 if unable to establish link
** UA if received frame is without poll

Fig. A1 -- Level 2 state table for command frames received

State	RR with Final	RR without F	REJ with Final	REJ without F	RNR with Final	RNR without F	UA either	DM either	FRMR either
S1 Disconnected									
S2 Link Setup							S5	S1	
S3 Frame Reject									SABM,S2
S4 Disconnect Rqst							S1	S1	
S5 Information Xfr	I	I	I	I	S9	S9		SABM,S2	SABM,S2
S6 REJ Frame Sent	I	I	I	I	S15	S15	SABM,S2	SABM,S2	SABM,S2
S7 Waiting Acknow.	I,S5	I	I,S5	I	S9	S12	SABM,S2	SABM,S2	SABM,S2
S8 Device Busy	I	I	I	I	S10	S10	SABM,S2	SABM,S2	SABM,S2
S9 Remote Device Busy	I,S5	I,S5	I,S5	I,S5			SABM,S2	SABM,S2	SABM,S2
S10 Both Devices Busy	I,S8	I,S8	I,S8	I,S8			SABM,S2	SABM,S2	SABM,S2
S11 Waiting Acknow. and Device Busy	I,S8	I	I,S8	I	S10	S13	SABM,S2	SABM,S2	SABM,S2
S12 Waiting Acknow. and Remote Busy	I,S5	I,S7	I,S5	I,S7			SABM,S2	SABM,S2	SABM,S2
S13 Waiting Acknow. Both Devices Busy	I,S8	I,S11	I,S8	I,S11			SABM,S2	SABM,S2	SABM,S2
S14 REJ Sent and and Device Busy	I	I	I	I	S16	S16	SABM,S2	SABM,S2	SABM,S2
S15 REJ Sent and Remote Busy	I,S6	I,S6	I,S6	I,S6			SABM,S2	SABM,S2	SABM,S2
S16 REJ Sent and Both Devices Busy	I,S14	I,S14	I,S14	I,S14			SABM,S2	SABM,S2	SABM,S2

Fig. A2 -- Level 2 state table of response frames received

State	Local Start Cmnd	Local Stop Cmnd	Station Becomes Busy	Busy Condition Clears	T1 Expires	T3 Expires	N2 is Exceeded	Invalid N(S) Received	Invalid N(R) Received	Unrecgd Frame Received
S1 Disconnected	SABM,S2									
S2 Link Setup		DISC,S4			SABM	SABM	S1			
S3 Frame Reject	SABM,S2	DISC,S4			FRMR	FRMR	SABM,S2			
S4 Disconnect Rqst	SABM,S2				DISC	DISC	S1			
S5 Information Xfr	SABM,S2	DISC,S4	RNR,S8		RR_c,S7	RR_c,S7		REJ,S6	FRMR,S3	FRMR,S3
S6 REJ Frame Sent	SABM,S2	DISC,S4	RNR,S14		RR_c,S7	RR_c,S7	SABM,S2		FRMR,S3	FRMR,S3
S7 Waiting Acknow.	SABM,S2	DISC,S4	RNR,S11		RR_c		SABM,S2		FRMR,S3	FRMR,S3
S8 Device Busy	SABM,S2	DISC,S4		RR,S5	RNR_c,S11	RNR_c,S11		RNR	FRMR,S3	FRMR,S3
S9 Remote Device Busy	SABM,S2	DISC,S4	RNR,S10		RR_c,S12	RR_c,S12		REJ,S15	FRMR,S3	FRMR,S3
S10 Both Devices Busy	SABM,S2	DISC,S4		RR,S9	RNR_c,S13	RNR_c,S13		RNR	FRMR,S3	FRMR,S3
S11 Waiting Acknow. and Device Busy	SABM,S2	DISC,S4		RR,S7	RNR_c		SABM,S2		FRMR,S3	FRMR,S3
S12 Waiting Acknow. and Remote Busy	SABM,S2	DISC,S4	RNR,S13		RR_c		SABM,S2		FRMR,S3	FRMR,S3
S13 Waiting Acknow. Both Devices Busy	SABM,S2	DISC,S4		RR,S12	RNR_c		SABM,S2		FRMR,S3	FRMR,S3
S14 REJ Sent and and Device Busy	SABM,S2	DISC,S4		RR,S6	RNR_c,S11	RNR_c,S11		RNR	FRMR,S3	FRMR,S3
S15 REJ Sent and Remote Busy	SABM,S2	DISC,S4	RNR,S16		RR_c,S12	RR_c,S12			FRMR,S3	FRMR,S3
S16 REJ Sent and Both Devices Busy	SABM,S2	DISC,S4		RR,S15	RNR_c,S11	RNR_c,S11			FRMR,S3	FRMR,S3

Note: S frames with the notation XXX_c are to be sent as commands, all others as responses

Fig. A3 -- Level 2 state table miscellaneous inputs

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